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NORDA's Pattern Analysis Laboratory: Current Contributions to Naval Mapping, Charting, and Geodesy

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Executive Summary

The Mapping, Charting and Geodesy (MC&G) Division at the Naval Ocean Research and Development Activity (NORDA) is the primary activity within the U.S. Navy for conducting research and development (R&D) in direct support of naval MC&G requirements. MC&G projects include R&D in the general areas of charting, remote sensing, bathymetry, geophysics, photogrammetry, reconnaissance, and ocean surveillance in support of the U.S. Navy, the U.S. Marine Corps, and the Defense Mapping Agency.

NORDA's Pattern Analysis Branch, MC&G Division, is concerned with all aspects of digital MC&G data, including hardware, software, and data bases. The primary computing facility of this branch is the Pattern Analysis Laboratory (PAL). This report describes the configuration of the PAL, its current and anticipated capabilities, and its role in naval MC&G projects.

Acknowledgments

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1.0 Introduction

The Pattern Analysis Laboratory (PAL) is the primary computing facility for the Mapping, Charting and Geodesy (MC&G) Division of the Naval Ocean Research and Development Activity (NORDA). The PAL is operated by the Pattern Analysis Branch, but is also utilized by the Advanced Sensor and Survey Branch. The PAL was originally configured in 1984 as a Remote Work Processing Facility (RWPF), one of three developed by the Defense Mapping Agency to be an integrated hardware/software computer system serving as a testbed for automated feature extraction research. One RWPF was located at the Army's Engineering Topographic Laboratory, a second at the Air Force's Rome Air Development Center, and the third at NORDA (Clark et al., 1986).

The RWPF projects have since been completed, and the computer facility has grown considerably. The PAL now satisfies most of the computing requirements of the MC&G Division. The tasks that require this computer facility fall under one of four general categories: digital image processing, computer graphics applications, general data processing, and office automation (Table 1-1).

Current computer-aided projects in the Pattern Analysis Branch include Coastal Image Understanding (CIU), Digital MC&G Data Analysis Program (DMAP), Map Data Formatting Facility (MDFF)/AV-8B, and World Vector Shoreline (WVS). Current computer-aided projects in the Advanced Sensor and Survey Branch include the Airborne Electromagnetic (AEM) Survey System and the Global Geomagnetics Project (GEM). Efforts that combine branch efforts to utilize the PAL are the Airborne Bathymetric Survey (ABS) system (including Hydrographic Airborne Laser Sounder (HALS) and Multispectral Scanner) and the Geophysical Airborne Survey System (GASS). This report will describe the PAL's roles in these projects and illustrate its potential for future MC&G projects.

Section 2 covers the physical configuration of the PAL, including major hardware components and networking. Section 3 describes software available to users. Section 4 gives examples of the PAL's many contributions, particularly in the areas of image processing and computer graphics. Previously untapped PAL resources are also discussed, including knowledge-based computers. Section 5 lists references. Detailed hardware and software lists are provided in appendices A and B.

Table 1-1. Computer-related tasks in NORDA's MC&G Division.

Digital image processing
Processing remotely sensed data
Image enhancement and understanding
Automatic feature extraction and pattern recognition
Computer graphics applications
Geographic Information Systems (GIS)
Graphical rendering of data models
Creating presentation-ready viewgraphs and slides
General data processing
Intensive mathematical calculations
Modeling data including bathymetry, magnetics, gravity, etc.
Word processing and office automation
Text editing—writing reports, articles, memos and letters
File organization—addresses, mailing labels, project files
Project management—Gandt charts, maintaining schedules
Financial spreadsheets

2.0 Physical Configuration of the PAL

2.1 Network Configuration and Communications

The PAL is physically and functionally divided into two areas: one is hosted by a VAX-11 series computer, the other is served by three connected workstations. All PAL computers are connected to the NORDA ethernet as shown in Figure 2-1. Table 2-1 lists the node address (a unique octal number assigned to a computer to identify it to other computers on the network) and the node name (an alphanumeric label that users substitute for the address when transmitting files between nodes) of each PAL computer. The term "node" usually refers to a computer on a network.

Table 2-2 lists the computer mailing addresses of a PAL user on the Space and Physics Analysis Network (SPAN) and Internet. SPAN is a DECnet network (linking computers that use the VAX/VMS operating system); Internet is a TCP/IP network (linking computers that use the UNIX ethernet protocol). Gateways exist between the two networks to permit files to be mailed, printed, or copied from one

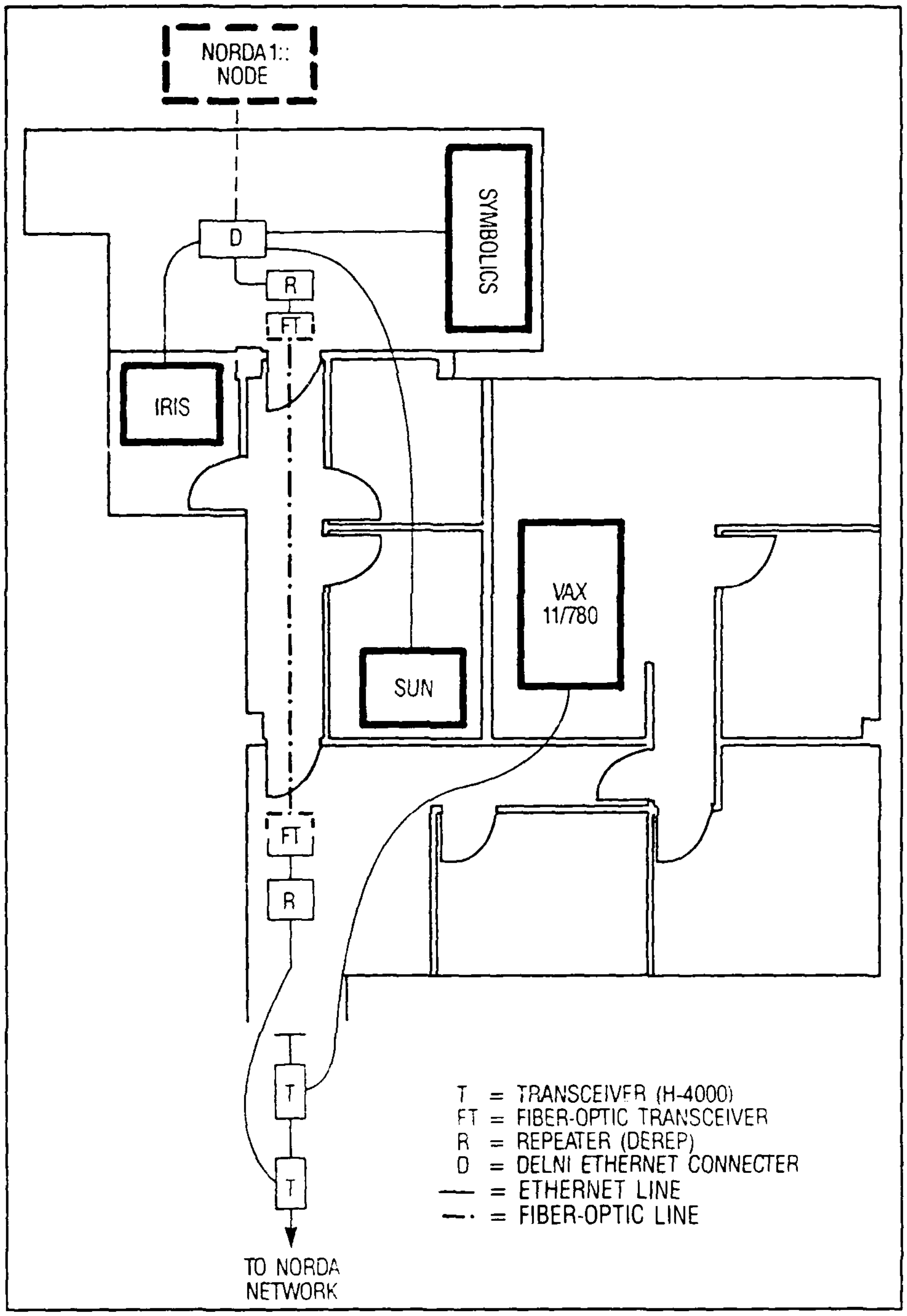


Figure 2-1. Network configuration of PAL computers.

Table 2-1. Network node names and addresses of PAL computers.

Computer	Node Name	DECnet Address	TCP/IP Address
VAX 11/780	A35	7.114	—
Silicon Graphics	IRIS	—	128.160.1.10
Symbolics	SYMBOL	—	128.160.1.11
Sun Microsystems	SOL	—	128.160.1.12

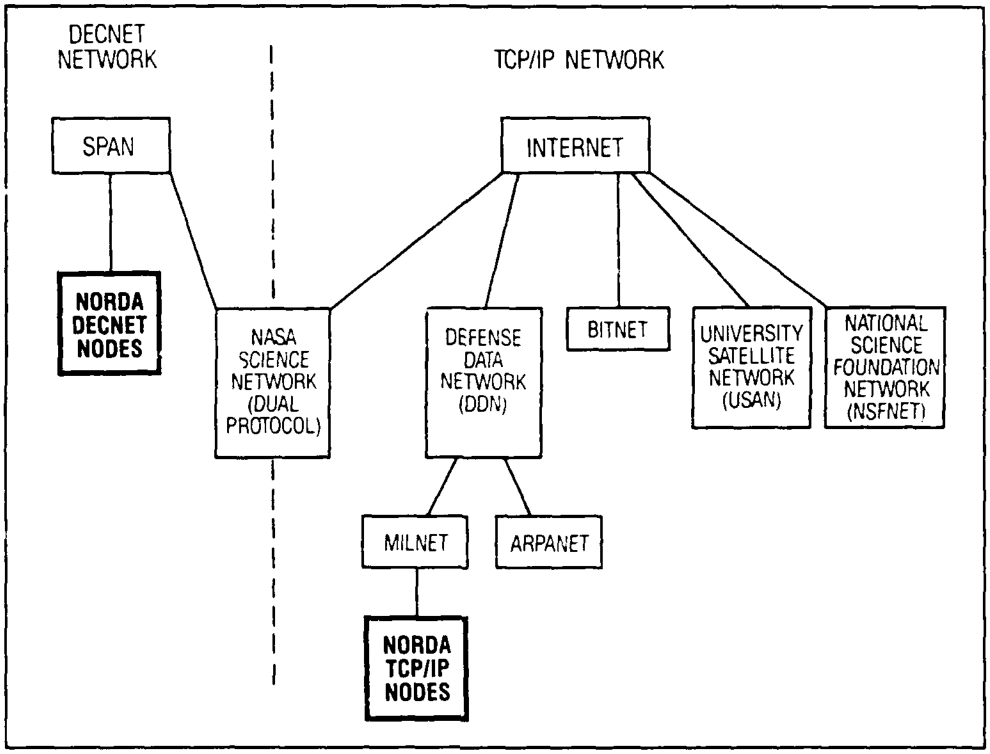


Figure 2-2. Major DECnet and Internet computer networks.

Table 2-2. MAIL addresses of a PAL user (BUGSBUNNY) on SPAN and Arpanet.

	VAX 11/780	Silicon Graphics
SPAN	A35::BUGSBUNNY	A33::MAILER! <BUGSBUNNY@IRIS>
ARPANET	bugsbunny%a35 .decnet@norda.arpa	bugsbunny@norda - iris.arpa

Note: Sun and Symbolics would be same as Silicon Graphics, but use SOL or SYMBOL (respectively) instead of IRIS.

computer to another (whether or not the communicating computers are nodes on the same network). Figure 2-2 shows the relationship between some of the more commonly used subnetworks of DECnet and Internet. Computer mail leaving NORDA for SPAN is simply addressed to NODE::USERNAME (where NODE is the node name of the receiving computer). For a list of usernames on any participating SPAN node, enter the command $ TYPE NODE:: USERLIST. Each system manager has been asked to prepare this list of users and make it available to the SPAN user community. For a list of SPAN nodes and addresses, enter the command $ PRINT SYS$SPAN: YELLOW_PAGES.LIS.

Computer mail leaving NORDA for an Internet node must be addressed through our mailer node:

A33::MAILER! <username@node> .

A33 is one of several NORDA nodes that allows both DECnet and TCP/IP protocols. Code 117's NORDA1 node is another VMS/UNIX gateway, and has been designated as NORDA's gateway between the two major networks. NASA is in the process of building the NASA Science Network, which will allow both protocols, and will be a primary gateway between SPAN and Internet (see Fig. 2-2).

An Internet node may actually be a combination of several nodes, separated by various delimiters, where the first is the user's end-node, and the others are gateway and mailer nodes. For example, to send mail to a user at the University of Washington (node name UWAV1), which is on Bitnet, the full address would be the following.

A33::MAILER! <username%uwavl.bitnet@oly. acs.washington.edu>

For more information regarding Internet addresses and specific commands to copy or print files between remote nodes, contact NORDA's ADP Resources Office, (601) 688-4827 or Autovon 485-4827.

This office is currently preparing a manual for users who wish to communicate with other DECnet and Internet nodes.

2.2 Physical Layout

The first major computing area in the PAL features the VAX 11/780 (node A35) running under the VAX/VMS operating system (Version 4.6). This area is somewhat restricted; personnel must either have a NORDA identification badge or be escorted by a NORDA employee for access. Classified processing is occasionally done in this area.

The second main computing area in the PAL is a more restricted, TEMPEST-cleared vault that contains several UNIX workstations: Graphics IRIS 3130 (node IRIS), Sun Microsystems 3/160-C (node SOL), and Symbolics 3670 (node SYMBOL). Only personnel with clearances of Secret or higher are allowed in the vault unescorted. The computers and vault have been cleared for up to Secret processing, but they are usually run in an unclassified mode. The workstations are networked to the NORDA ethernet via fiber-optic cabling to eliminate any electrical emissions when disconnected for classified tasks. These specialized workstations are connected to the NORDA ethernet via a TCP/IP gateway in Code 117's VAX (node NORDA1) running ULTRIX.

2.3 VAX 11/780 and Peripherals

Figure 2-3 illustrates the hardware configuration of the VAX 11/780. Appendix A includes the major hardware components and peripherals on this VAX. The hardware can be broken into five main categories: image processing and raster graphics devices, vector graphics devices, floating point processor, mass storage devices, and data transport devices.

Figure 2-4 illustrates the major differences between vector and raster data. A raster image requires a point value for each dot, or picture element (pixel), in the

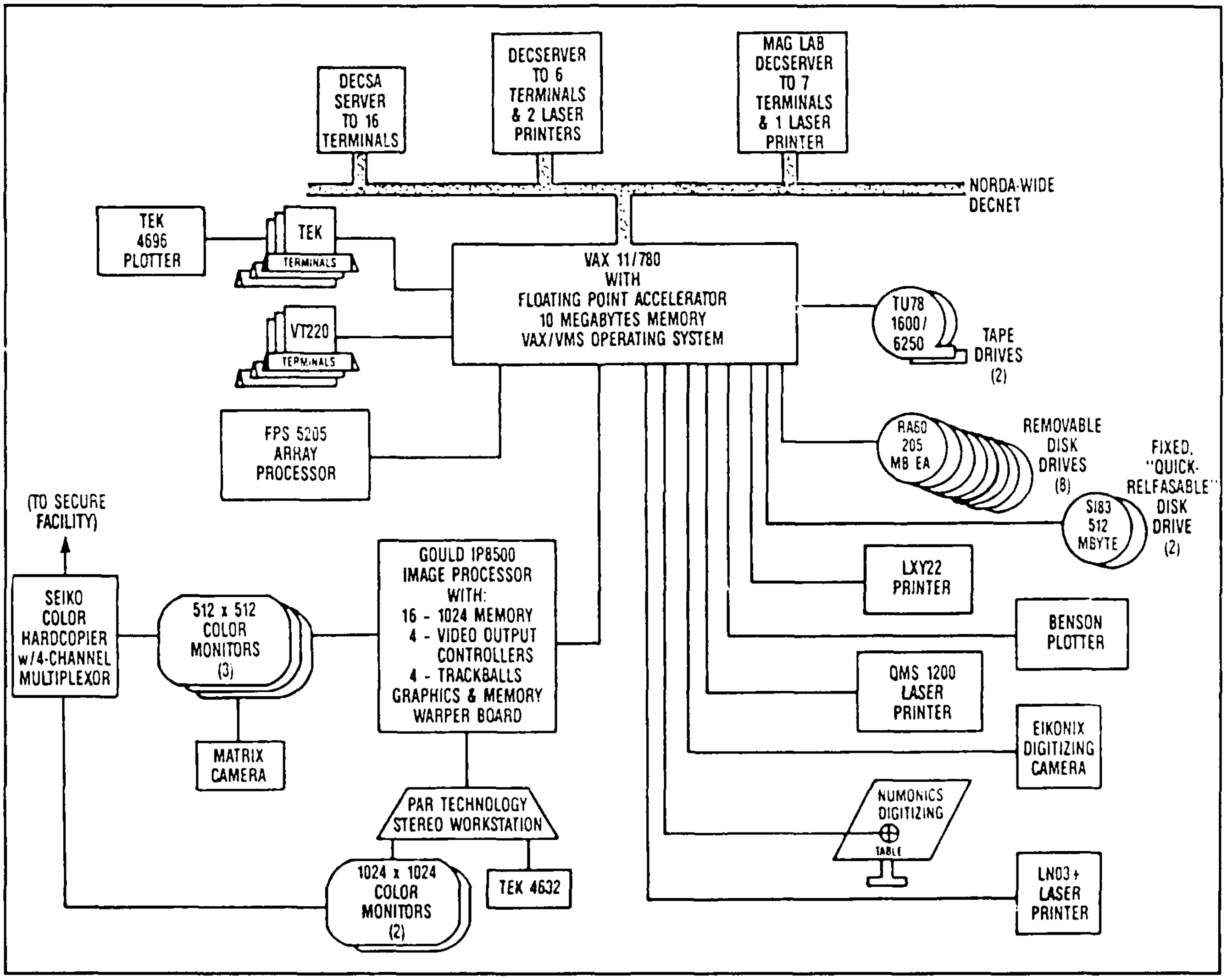


Figure 2-3. PAL VAX 11/780 hardware connectivity chart.

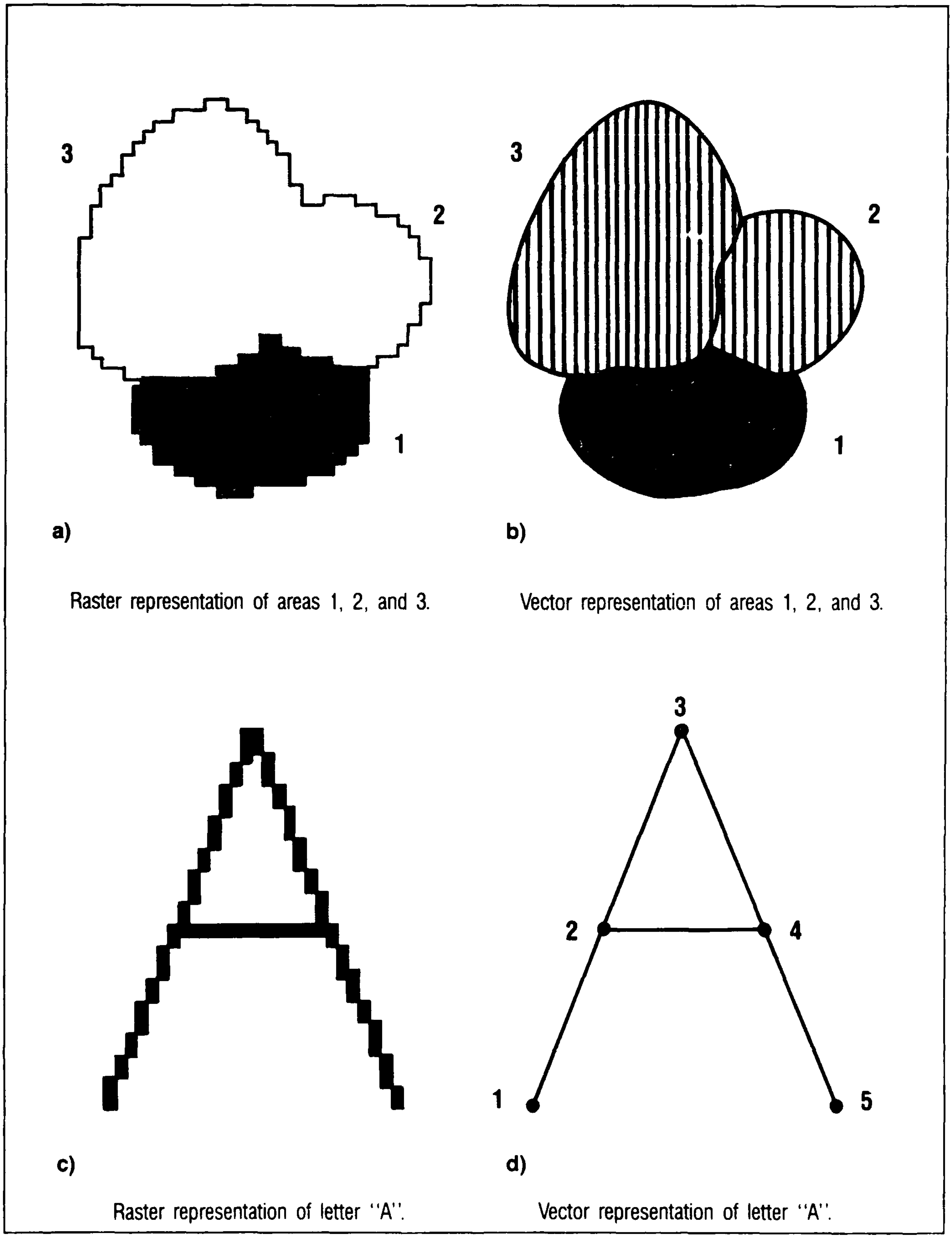


Figure 2-4. Raster and vector representations of graphic data.

area of interest, but a vector image requires only point values where data actually exist. Isolated points and linear features are most efficiently represented by vector data and are most realistically plotted by vector devices; areal features are best represented by raster data. Raster devices can display vector data, but as the resolution (i.e., maximum number of pixels/inch) of a raster device decreases and pixel size increases, straight lines become more jagged and text becomes harder to read. Likewise, vector devices do not display raster data very well, if at all.

2.3.1 Raster Graphics and Image Processing Devices

Our biggest VAX peripheral, both in capacity and in utilization, is a Gould IP8500 image processor. As a raster graphics device, it is used to perform numerous computer-aided mapping tasks, such as processing remotely sensed images (illustrated in section 4). The Gould can drive up to four low-resolution (512 × 512 pixels) image-processing workstations or one high-resolution (1024 × 1024 pixels) workstation, and is equipped with a total of 20 memory boards (512 × 512 bytes each). Our present configuration allots five memory boards to each of four low-resolution workstations: three boards are typically used to process and display the red, green, and blue (RGB) components of a color image; the fourth board is used for graphic and alphanumeric overlays; the fifth board is used as a "scratch pad." Alternatively, it is possible to allot all 20 memory boards to a single workstation (four boards for each of the RGB channels, four for graphics, and four for "scratch"), resulting in a high-resolution 1024 × 1024 raster image.

An Eikonix digitizing scanner inputs graphic data in raster form. This scanner has a 55-mm Nikon camera lens that takes a digital picture of a map or a photograph in its viewport and records the image in three 512 × 512 matrices of pixel values. Each matrix corresponds to one of the primary photometric colors (RGB). A raster image that has been scanned by the Eikonix can then be processed (enhanced, scaled, or otherwise manipulated) and displayed with the Gould.

Raster graphic hardcopy output is provided by a Matrix camera, which gives Polaroid color transparencies or photographs, and by a Seiko color hardcopier, which also produces both transparencies and paper output. Both devices collect data via RGB video connections to a color monitor. The image portrayed on the monitor is depicted on the final print. The Matrix camera is connected to a Gould monitor, and the Seiko has a multiplexer with four ports: one to each of two Gould monitors, one to the IRIS color display monitor, and one to the Symbolics color monitor. The Matrix produces much better pictures, but the Seiko is much faster, easier, and less expensive to use.

In addition, several laser printers are connected to the VAX 11/780 for black/white graphics and high-quality text output. Although these are primarily raster devices, vector data may be reproduced quite well by these printers, since they have a relatively high resolution (300 pixels per inch, or 90,000 pixels per square inch).

Several Tektronix color terminals (4107 and 4208 models) are available for softcopy color graphics. A Tektronix 4696 color ink jet plotter is connected to one of the 4107 terminals for hardcopy output. This color plotter provides lower resolution (120 pixels per inch, or 14,400 pixels per square inch) than the laser printers, but it still makes fairly good vector drawings in addition to producing very good raster graphics.

2.3.2 Vector Graphics Devices

A Numonics digitizer inputs vector graphic data by sensing the X,Y locations of points from an electronic digitizing table and transmitting the values to the VAX, where they are stored in a user's file. The Numonics may be used in conjunction with the Gould image processor to register specific points from a paper chart to an image of the same area displayed on the Gould. In this way, a Gould image may be geographically warped to some desired map projection, or data points and values (such as bathymetric soundings) from a paper chart can be added to a raster image. This last technique has been used to interpolate bathymetry from the patterns and colors on a satellite image (as shown in section 4). Vector data that have been digitized on the Numonics, such as coastlines or political boundaries, can be overlaid on a raster Gould image using the Gould's special graphic overlay channel.

A Benson plotter is used to plot vector graphic data that have been digitized on the Numonics or derived from some other source. The plotter supports rolls of paper (38.2 inch wide × 164 feet long) for producing large plots or multiple small ones. Up to eight colored, felt-tip pens may be used simultaneously; rapidograph liquid ink pens are also available for finer line drawings.

2.3.3 Floating Point Array Processor

The other major processor connected to the VAX 11/780 is a Floating Point Systems (FPS) arithmetic array processor (AP). The AP works in parallel with the VAX 11/780 to perform large numbers of reiterative multiplications and additions, useful in digital signal processing, matrix arithmetic, statistical analyses, and numerical simulation.

The highly parallel structure of the AP allows the overhead of array indexing, loop counting, and data input from memory to be performed simultaneously with arithmetic operations on the data (Floating Point Systems, 1984). This structure not only allows much faster execution than on the VAX alone, but also frees the VAX for other computer operations.

2.3.4 Mass Storage Devices

Disk storage on the VAX 11/780 is always at a premium; as on most computers, it seems that users' file storage requirements will always expand to fill the available disk space. The PAL currently has eight RA60 removable disk drives and two Systems Industries "fixed but quick-releasable" disk drives, for a total storage capacity of about 2.6 gigabytes. The PAL is restricted to using disk drives that are user-removable to maintain the current security rating for occasional classified tasks.

2.3.5 Data Transport Devices

The VAX 11/780 currently has two tape drives, both running at 1600 or 6250 bytes per inch (bpi). The NORDA ethernet also provides data I/O capabilities, and provides a gateway to SPAN, Bitnet, Arpanet, Defense Data Network (DDN), and other computer networks, as shown in Figure 2-2. Six Data Interface Unit (DIU) modems (supporting baud rates of up to 19200) and one analog modem (supporting baud rates of 300 and 1200) are available for communication to terminals with no access to one of these networks. The analog modem can be programmed to call an off-site terminal (i.e., the terminal's modem must not be on a Stennis Space Center telephone line); the digital modems can only reliably receive calls, they cannot place calls.

2.4 Secure Facility—UNIX Environment

Figure 2-5 illustrates the hardware configuration of the Secure Facility (detailed in Appendix A). Three UNIX workstations reside in this facility and communicate with one another via TCP/IP: Silicon Graphics IRIS 3130, Sun 3/160-C, and Symbolics 3670. Like DECnet for VAX/VMS computers, TCP/IP allows a user to mail, copy, or print a file from one UNIX computer to another. It also allows a user that is logged into one computer to log into another computer from the same terminal. A Network File System (NFS) software package, installed on each of these computers, allows the computers to share disk and tape resources. These three UNIX workstations are described in more detail below.

2.4.1 Silicon Graphics IRIS 3130

The IRIS workstation provides high-speed, high-quality, three-dimensional graphics capabilities. Graphic primitives are programmed in firmware, as opposed to software, resulting in much faster rendering. Graphic primitives include two- and three-dimensional transformations (rotation, translation, scaling); calculations for Bezier, B-spline and Cardinal spline curves and surfaces; and Gouraud shading, transparency, and multiple light sources.

The IRIS runs under the UNIX operating system, with both Berkeley 4.2 and AT&T System V enhancements. Both Bourne and C shells are available. It uses the TCP/IP ethernet protocol, and is linked to the NORDA ethernet (as node IRIS) via the VAX/ULTRIX gateway in node NORDA1.

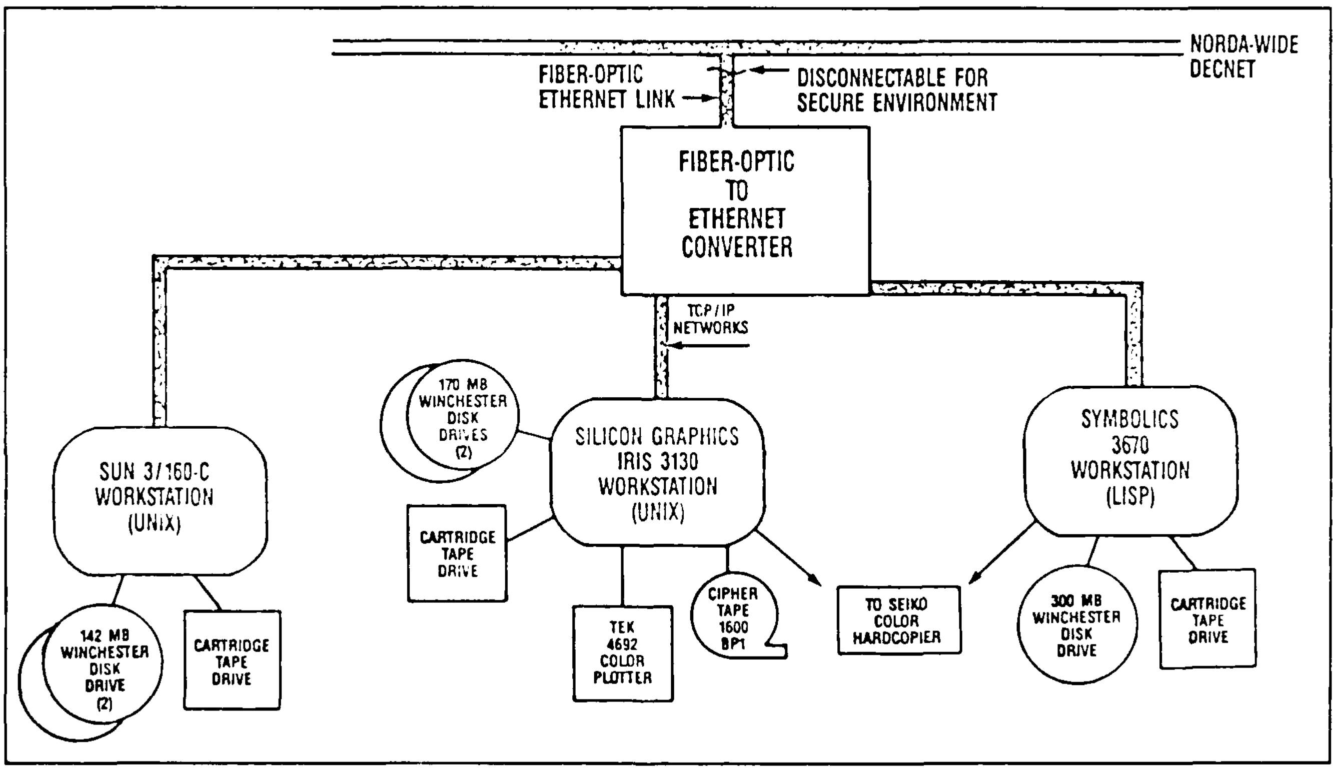


Figure 2-5. PAL Secure Facility: hardware connectivity chart.

A color monitor on the IRIS provides advanced windowing capabilities and high-resolution (1024 × 768) graphics. Other peripherals include a Tektronix 4692 color ink-jet printer ('154 pixels per inch resolution), cartridge tape drive, 9-track tape drive (1600/3200 bpi), and two Winchester disk drives (with a total of 340 Mbytes storage). Four RS232 ports and an ethernet line provide additional user access. The IRIS is connected to one multiplexer port on the Seiko color hardcopier.

2.4.2 Sun 3/160-C

The Sun 3/160-C workstation also provides high-quality graphics, although it is not as fast or as advanced as the IRIS. It runs under UNIX Berkeley 4.2 and uses the Bourne shell. The Sun, a user-friendly interface for specialized image processing applications, will be used in conjunction with the Gould image processor (via ethernet from the VAX 11/780). It is also used for Geographic Information Systems (GIS) applications (section 3).

Peripherals connected to the Sun are limited to two disk drives (140 Mbytes each) and a cartridge tape drive, but it is connected to the NORDA ethernet as node SOL via the VAX/ULTRIX gateway in node NORDA 1. Disk, printer and terminal devices can be shared via ethernet.

2.4.3 Symbolics 3670

The Symbolics 3670 workstation runs under the LISt Processing (LISP) language and operating system, and is used for Artificial Intelligence (AI) applications. The Symbolics has a black/white monitor for menu-driven programming and system operations, an RGB color monitor (512 × 512 pixels) for color graphics, one Winchester disk drive (300 Mbytes), and a cartridge tape drive. The color monitor is connected to one port on the Seiko for color video output, and the computer supports TCP/IP ethernet protocol for network transactions via the NORDA1 gateway (nodename SYMBOL).

3.0 Software

Software packages currently available in the PAL are listed by application in Appendix B. A quick guide to accessing the software and a list of on-line help is also given. This section will describe in more detail some of the MC&G-specific software available, including image processing software, GIS and other graphics packages, math and statistics functions, and miscellaneous utilities.

3.1 Image Processing

The Library of Image Processing Software (LIPS) is an image-processing software package written for the Gould IP8500, and includes the basic utilities required to perform many image-processing tasks. However, it is limited in scope, not very user-friendly, and somewhat lacking in good documentation. Therefore, LIPS has generally been used to debug or troubleshoot the Gould in the PAL, but has not been used much for image processing.

The primary image-processing package used in the PAL is a public-domain software program written by NASA's Earth Resources Laboratory (ERL), called the ERL Application Software (ELAS). ELAS has a Gould driver and has been adapted for specific image-processing tasks in the PAL. Standard ELAS operations include the following: deriving training statistics for an image; classifying imagery data using maximum likelihood and other schema; registering an image to another image or to a paper map (using digitizer input); manipulating polygons that define specific areas on the image; concatenating data sets; implementing on a pixel-by-pixel basis any programmable algorithm; and performing statistical analyses (such as regression and correlation) of multivariate data sets (NASA, 1987). ELAS is currently available for both our VMS and ULTRIX operating systems, although only the VMS version is complete.

The Automatic Feature Extraction System (AFES) is an image-processing package used by DMA for their Remote Work Processing Facilities (RWPF) and is UNIX-based. It was designed by Par Technology Corporation as a testbed for applying image processing, photogrammetry, and pattern recognition techniques for semiautomatic map generating and updating (Par Technology Corp., 1981). AFES is capable of handling both digital and film sources. It is supposed to be user-friendly enough to be operated by persons unfamiliar with computers.

The Earth Resources Data Analysis System (ERDAS) is another image-processing package running in the PAL. ERDAS performs image analysis of remotely sensed multispectral data (such as Landsat and other satellite images), video-digitized image data (such as aerial photographs), and gridded polygon data (digitized soils maps or topographic maps). ERDAS also provides geographic analysis functions, including a GIS package, a digitizer interface, and a mapping package for color hardcopy map output to a Tektronix 4696 plotter (ERDAS, 1986). The key benefit of ERDAS is that it comes in both VMS-based and PC-based versions. An imaging application can be performed on the VAX and then transferred to a fieldable IBM-PC/AT or compatible computer. Likewise, large images can be processed on the VAX, and smaller subsets of the image can be downloaded for processing on a PC.

3.2 Geographic Information System

NORDA's DMAP project has ported a public-domain GIS package, called the Geophysical Resources Analysis Support System (GRASS), to the Sun workstation. GRASS provides the MC&G Division with a high-quality GIS package for evaluating and displaying various geographic data, such as DMA's Digital Terrain Elevation Data (DTED), Digital Feature Analysis Data (DFAD), World Vector Shoreline (WVS), Multispectral Imagery, and other data sets. Sample maps produced with GRASS on the Sun, for the DMAP project, are included in section 4 of this report. In addition to the Sun, GRASS will soon be available for IRIS and Macintosh workstations. The State of Mississippi's Institute for Technology Development (ITD), located at Stennis Space Center, is responsible for distributing GRASS to users in this area.

3.3 Other Graphics

In addition to GRASS, the DMAP project has installed several other public-domain graphics packages on the Sun and IRIS to interactively display various MC&G data. The Terrain Perspective Viewer (TPV), written for the Sun workstation by the Rome Air Development Center, displays DMA's DTED data in two and three dimensions from user-chosen viewpoints above the terrain. TPV also varies the light source to simulate views at different times of the day. Section 4 of this report provides an example of TPV's output plots. Another demonstration mapping program has been written by the Naval Surface Weapons Center to display the shorelines of the United States east coast (from the Central Intelligence Agency's World Data Bank II), bathymetry (from DMA's Digital Bathymetric Data Base), and elevation data (from DMA's DTED).

Graphics software libraries are available for most of the PAL's graphics hardware. Most are FORTRAN subroutines that must be called from a user's program. The Benson plotter has a Calcomp-compatible library of plot calls, including routines to draw lines, set up axes, plot sets of X-Y points, draw characters and symbols, and scale the plot. The Tektronix PLOT-10 library (resident on the VAX 11/780) provides a similar set of routines for Tektronix terminals. Graphical Kernel Standard (GKS) enhancements to PLOT-10 are also resident on the VAX 11/780.

Graphic programmers in the PAL often choose a package written by the National Center for Atmospheric Research (NCAR). The NCAR package includes drivers for many devices in the PAL, including the laser printers and Tektronix terminals. Writing a driver for the Benson plotter would be a relatively easy step, if required. NCAR also provides some three-dimensional transformations not available in the other packages.

For more sophisticated graphics, however, the PAL's Silicon Graphics IRIS computer is nonpareil. This machine was designed for high-speed, state-of-the-art three-dimensional computer graphics. The IRIS comes with a large library of two- and three-dimensional routines and a tutorial that guides new users through the basics of creating computer graphics on this computer. Although written in C language, these routines may be called from either C or FORTRAN programs. Program Render is a portable computer-mapping program that has been transported to the IRIS (DMAP, 1988; Landrum, 1988). Sample plots produced by Render for the DMAP project are shown and described in section 4 of this report.

3.4 Math and Statistics

The FPS array processor has an extensive library of FORTRAN-callable mathematical routines that utilize the fast computing capabilities and the extended memory of the FPS. Among the many operations available include the following: vector manipulation (add, subtract, multiply, divide, scalar product); matrix manipulation (add, multiply, transpose); and Fast Fourier Transform (FFT) operations (two-dimensional complex FFT, and real to complex FFT).

The IMSL library is a set of computational subroutines written in FORTRAN for solving various mathematical and statistical problems. A list of the general subroutine categories is given in Table 3-1.

3.5 Miscellaneous Utilities

In addition to the commercial and public-domain software available, the PAL boasts some excellent locally written software and software from the Digital Equipment Corporation Users' Group (DECUS) library. Some of the more useful utilities are described here: DIALER, DTC, FRED, FTCOPY, FINDDEV, FINDTAPE, WHOIS.

Table 3-1. General categories of IMSL subroutines (from IMSL, 1984).

Analysis of Variance
Basic Statistics
Categorized Data Analysis
Differential Equations; Quadrature; Differentiation
Eigensystem Analysis
Forecasting; Econometrics; Time Series; Transforms
Generation and Testing of Random Numbers
Interpolation; Approximation; Smoothing
Linear Algebraic Equations
Mathematical and Statistical Special Functions (Probability Distribution Functions; Mathematical Physics)
Non-Parametric Statistics
Observation Structure; Multivariate Statistics
Regression Analysis
Sampling
Utility Functions (Error Detection; I/O Routines)
Vector-Matrix Arithmetic
Zeros and Extrema; Linear Programming

DIALER is a dialing program to call off-site computer terminals. It uses the Hayes Smartmodem (device line TTA7:) only, and will not work with the digital modem lines. For example, a user may run DIALER to call a modem connected to a terminal at home after hours. To do this, write a command file (DIALHOME.COM) containing the following lines:

```
$ RUN AUTO_DIAL:DIALER
  1200
  phone_number
$ EXIT
```

where phone_ number is the number of the modem being called. A comma "," can be used to signal a pause in dialing the number. To execute DIALHOME.COM at a certain time, submit it to batch and specify the time to call:

```
$ SUBMIT/AFTER = 1900 DIALHOME.COM
```

DIALHOME.COM will be executed at about 7:00 p.m. that evening.

DTC (Desk Top Calendar) is a utility from a DECUS library tape (Wyle et al., 1984). Each user maintains their own DTC file of personal appointments. To use, type $ DTC. A help menu will explain how to create, view, and update daily entries and how to view weekly and annual agendas.

FRED (Fast and Reliable Editor) is also available from the DECUS library. It was written with DEC's Text Processing Utility (TPU) (Wischow, 1987). In addition to most of the more well-known EDT editing commands, FRED includes dual-window editing (allowing user to view more than one file, or two sections of the same file at the same time), margin adjusting, ability to draw boxes around blocks of text (viewgraph potential), rectangular cut/paste, and write-protection of edited files. For more information, type $ FRED and then press the HELP key.

FTCOPY (Foreign Tape COPY), copies tapes that often cannot be copied using the VAX COPY command. FTCOPY allows blocking and unblocking of data, specifying record and block sizes, translations between EBCDIC and ASCII, and various other tape manipulations. This program is also available from the DECUS library (Woods Hole Oceanographic Institution, 1986). For more information, type: $ HELP FTCOPY on node A35.

FINDDEV, FINDTAPE, and WHOIS are utilities to print out pertinent information about devices, tapes, and users, respectively (Lohrenz, 1987a; Lohrenz, 1987b; Lohrenz, 1987c). FINDDEV lists the devices on A35, including terminals, disk drives, tape drives, and printers. The device name, type, location and nearest phone extension are given (useful for finding the current user of a terminal line, for example). FINDTAPE lists the tapes in the PAL tape library by index number, tape rack location, owner, read/write status, and description. WHOIS lists specified SPAN users by username, full name, phone extension and office building. The user list is updated with the addition of every new user on node A35, and annually for other participating nodes.

4.0 Using PAL Computers for MC&G Applications

Central Processing Unit (CPU) usage of the PAL's main computer, the VAX 11/780, has increased dramatically over the past 3 years, as Code 350 scientists have come to realize the benefits of computer-aided MC&G. As shown in Figure 4-1, usage has more than tripled since 1985 from under 20 CPU hours per month to about 65 CPU hours/month, and the number of full-time users (excluding system manager- and operator-related accounts) has also tripled from 18 to 59. What are all these users doing? The following paragraphs summarize each of the major MC&G projects that make use of PAL resources. Specifically, PAL contributions are highlighted for the ABS, AEM, CIU, DMAP, GEM, GASS, MDFF, and WVS projects.

4.1 Airborne Bathymetric Survey System

NORDA is developing the Airborne Bathymetric Survey (ABS) system to conduct bathymetric surveys in coastal waters. The ABS consists of two major

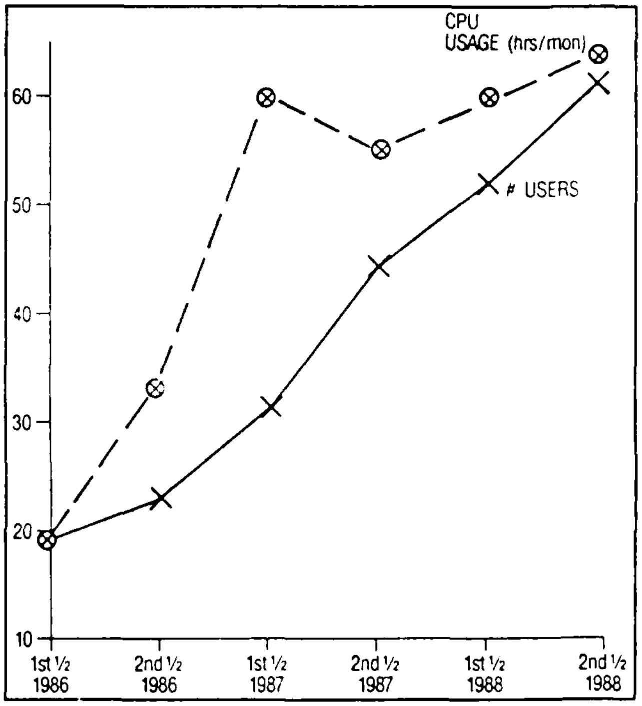


Figure 4-1. Graph of CPU usage on PAL VAX 11/780 over past 3 years.

components: a Hydrographic Airborne Laser Sounder (HALS) and a multispectral scanner (known as the NORDA Scanner). The HALS is near completion and is currently undergoing system integration and flight tests (Guenther and Mesick, 1988). The NORDA Scanner is also nearing the testing phase of development. NORDA plans to integrate the two into one operational system in 1989 (Haimbach et al., 1988).

The objective of NORDA's developmental efforts is to build a system that is capable of rapidly charting coastal bathymetry from an aircraft and to provide the algorithms and computer software necessary to process the data. These algorithms and software are installed and running on the PAL's VAX 11/780. The PAL's FPS array processor is being implemented to speed up the computer-intensive algorithms; the Gould IP8500 is being used to view and process images output by the NORDA Scanner (Fig. 4-2); various plotters and graphics software (particularly NCAR) are used to plot digitized waveforms, navigational data, and contour plots of bathymetric data output by the laser sounder. In addition, several PAL disks are required to store working and test imagery data.

Although the testing phases of the ABS project are near completion, the PAL could still be used over the next few years to investigate new image-processing methods and improved ways to determine bathymetry from the NORDA Scanner imagery.

4.2 Coastal Image Understanding

The Coastal Image Understanding (CIU) project is studying methods of extracting water depths from near-shore satellite imagery, and has achieved accuracies to within 2 m from Landsat Thematic Mapper (TM) imagery. Several different algorithms were used to calculate water depth: single-band, dual-band ratio, and linear multiband methods. The multiband method proved to be superior, since it does not require bottom-type clustering and classification that is required by the other methods (Clark et al., 1987). A new image destriping technique was also developed to remove noise stripes in certain bands of the image, enhancing the visual perception of the image. CIU is also investigating methods of classifying features for terrain analysis in the coastal region.

The CIU project uses the PAL's VAX 11/780 and Gould image processor to display and process the imagery data, and uses the FPS array processor to execute algorithms for determining water depths. In addition, a large portion of the PAL's disk space is required for storing working imagery data, and a large proportion of the tape and disk libraries hold more images. Figure 4-3 shows two images of Isla de Vieques: (a) true color (original Landsat image displaying unprocessed RGB bands) and (b) bathymetry contours (derived from the original image using a multiband algorithm).

4.3 Airborne Electromagnetic Studies

Experimental Airborne Electromagnetic (AEM) survey data collected in Cape Cod Bay in 1984 are used in this project to derive continuous profiles of water depth, electrical depth, water conductivity, and bottom sediment conductivity. The conductivity data are then used to derive density, porosity, sound speed, and acoustic reflectivity of the ocean bottom. (Won and Smits, 1986). These profiles are calculated on the PAL's VAX 11/780 with algorithms that implement statistical functions from the IMSL mathematic and statistic subroutine library.

4.4 Digital MC&G Data Analysis Program

The Naval Digital MC&G Data Analysis Program (DMAP) consists of scientific, engineering, cartographic, and geographic analysis capabilities supported by the PAL's hardware and software computing resources. DMAP scientists assist in identifying data requirements for prototype systems during the early stages of the development cycle. DMAP serves the Navy in four major areas: new product evaluation, technical coordination, ongoing requirements analysis, and software development. The PAL is a principal tool in these areas, but particularly in software development. The DMAP's official brochure *(The Naval DMAP: Coordination for the Navy's Use and Development of Digital MC&G Data)* clearly states the PAL's role in this project:

The DMAP will require substantial software support for its operation. Many of the DMAP's responsibilities center around providing support for Navy digital data operations through information exchange and product evaluation. The DMAP must provide for the storage and interactive retrieval of text and graphics-based data files descriptive of existing software systems and data products. It must also provide an adequate means to evaluate and identify the digital MC&G data needs of the Navy. ...The current capabilities of the PAL computer facilities are generally well suited to support the requirements of the DMAP [since] the PAL contains a variety of state-of-the-art computers, image processors and graphics workstations.

Several of DMAP's software acquisitions were mentioned earlier in this report, such as the GRASS GIS system and the TPV terrain display program. Figure 4-4 depicts a series of GIS map overlays created and displayed with GRASS on the PAL's Sun 3/160-C workstation; Figure 4-5 shows an output frame (two- and three-dimensional views of DMA's DTED) from the TPV program, also on the Sun. Figure 4-6 shows frames from the Render program as displayed on the IRIS 3130 workstation. The DMAP project is expected to continue to grow over the next several years, as is the PAL's role in its development.

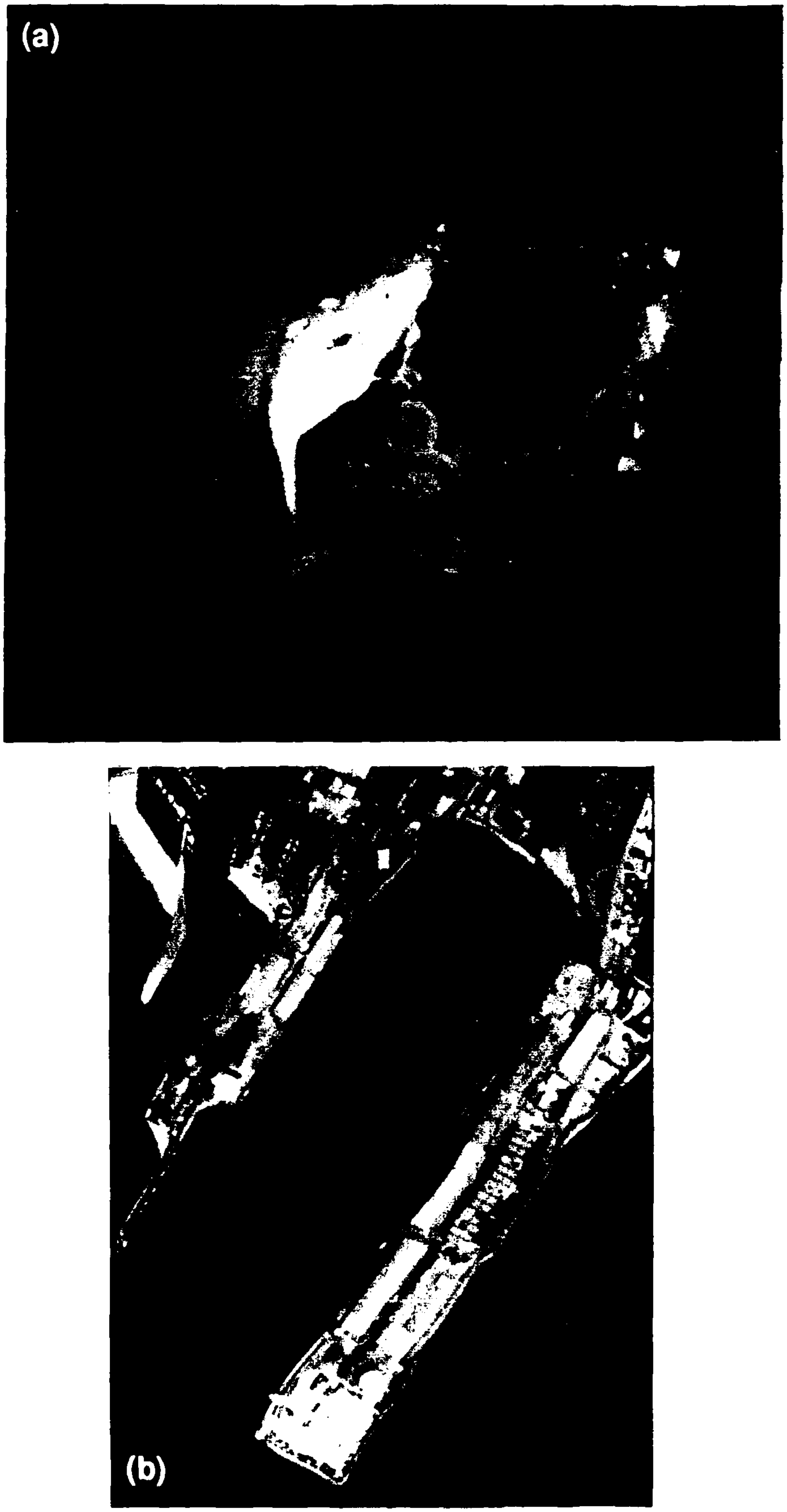


Figure 4-2. NORDA Scanner images: (a) Pelican Shoal off Key West, Florida; (b) pier in Gulfport, Mississippi.

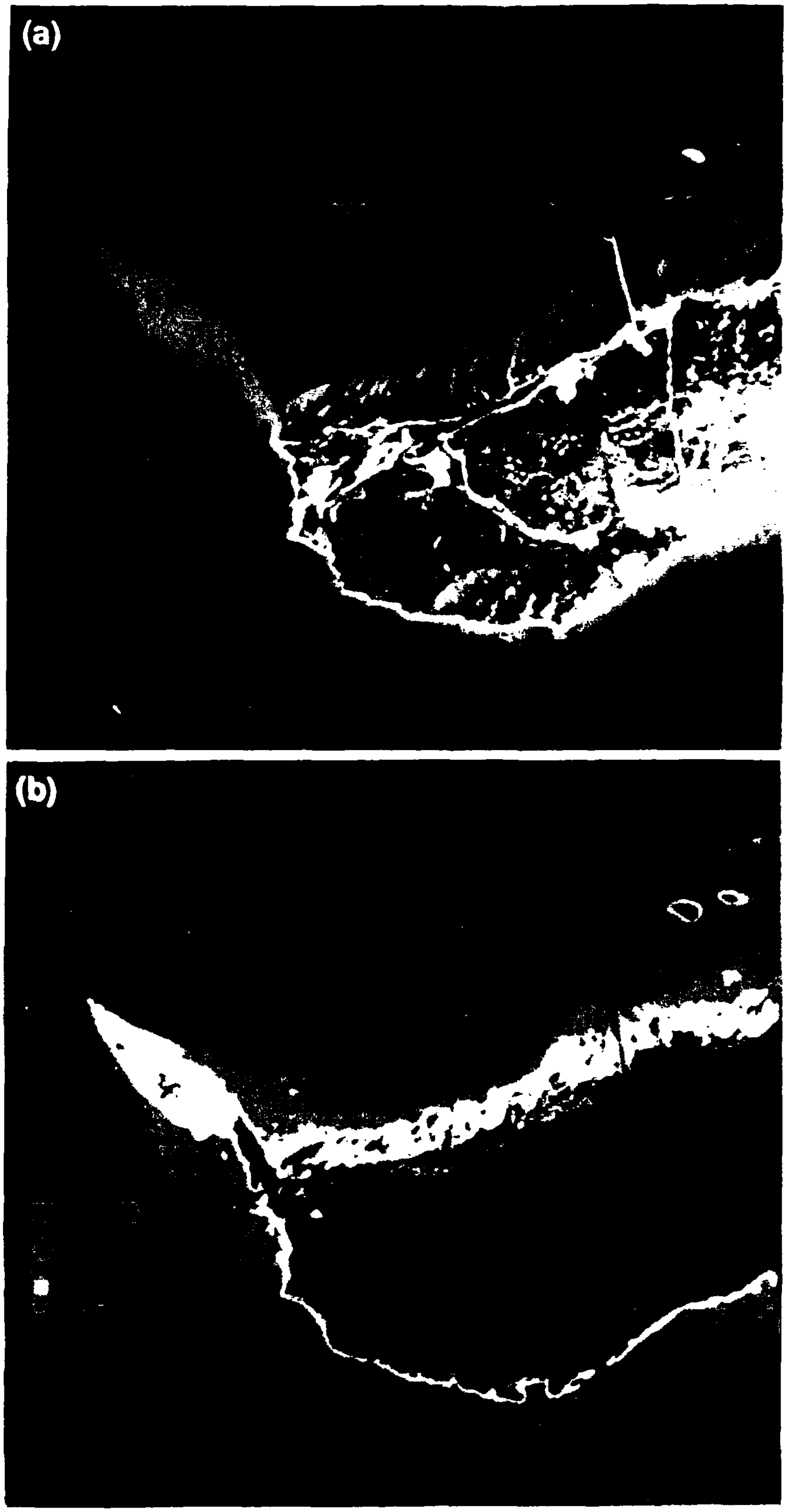


Figure 4-3. Isla de Vieques images: (a) true color LANDSAT image; (b) bathymetric contours derived from LANDSAT image.

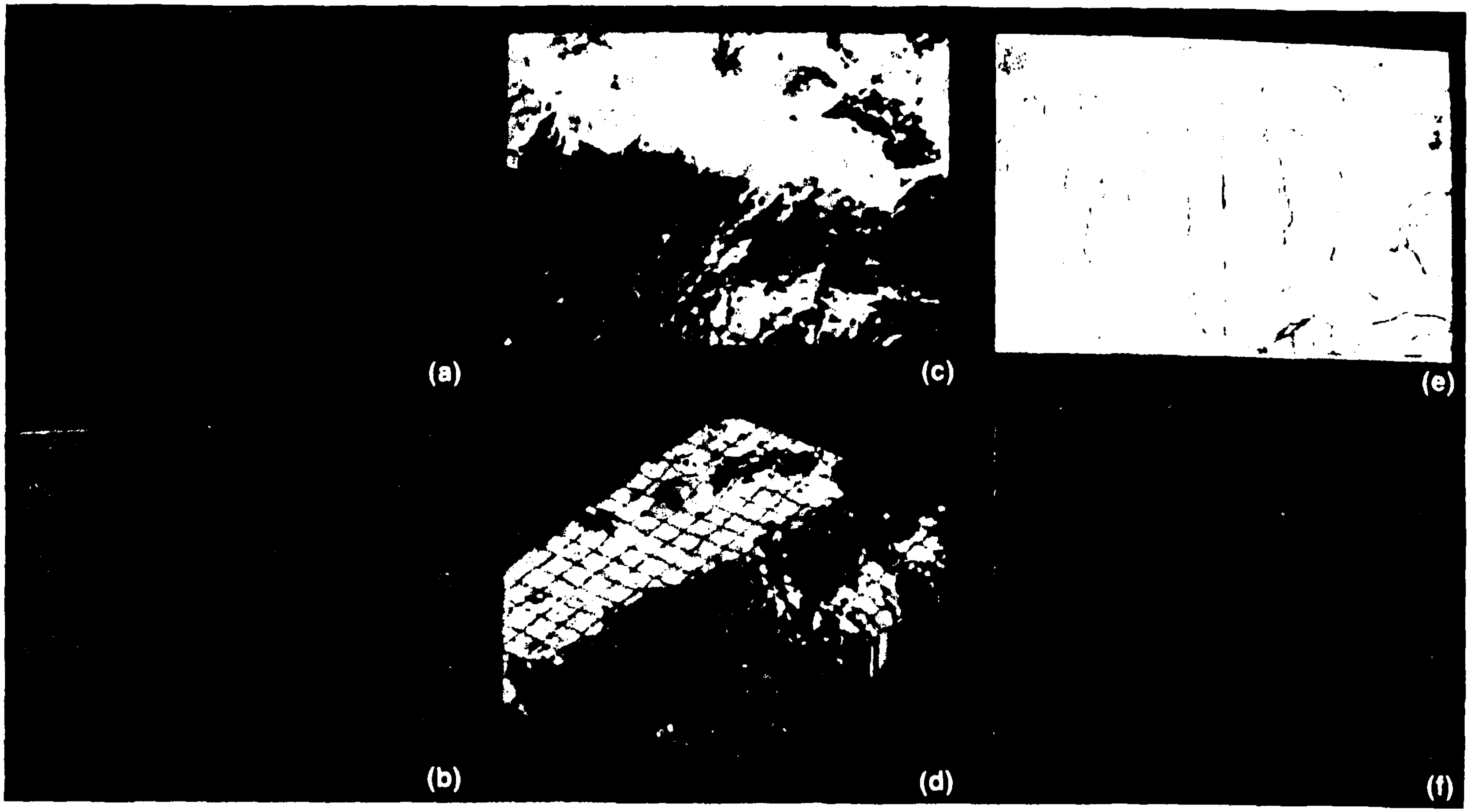


Figure 4-4. Sample map overlays created with GRASS GIS software on the Sun Microsystems 3/160-C computer: (a) Elevation data from DMA; (b) Slope data, derived from elevation map (a); (c) Imagery from Multispectral Scanner (MSS); (d) 3-D view of MSS imagery (c), using elevation map (a) for z values; (e) Roads (red) and streams (blue) from USGS DLG-3 data base; (f) Distance from streams, derived from map (e).

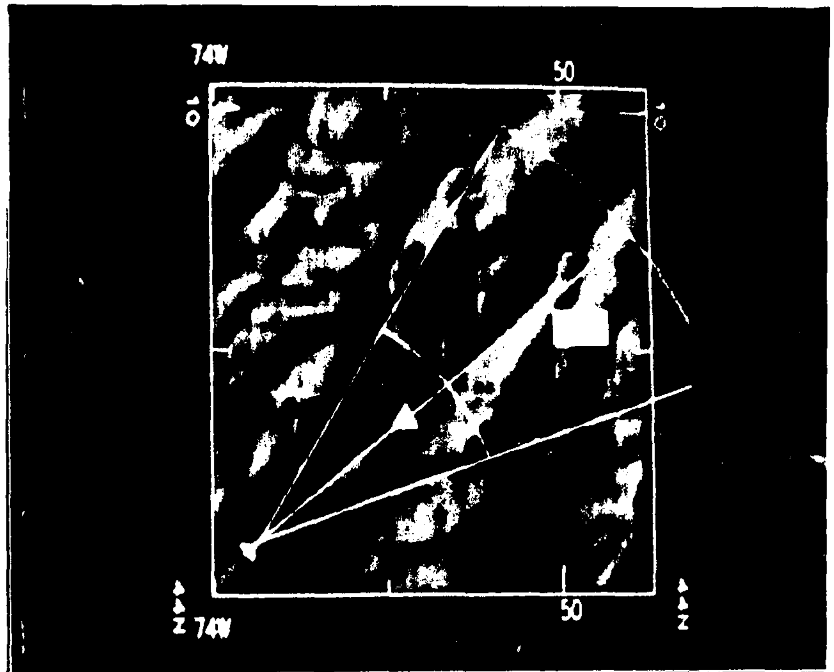
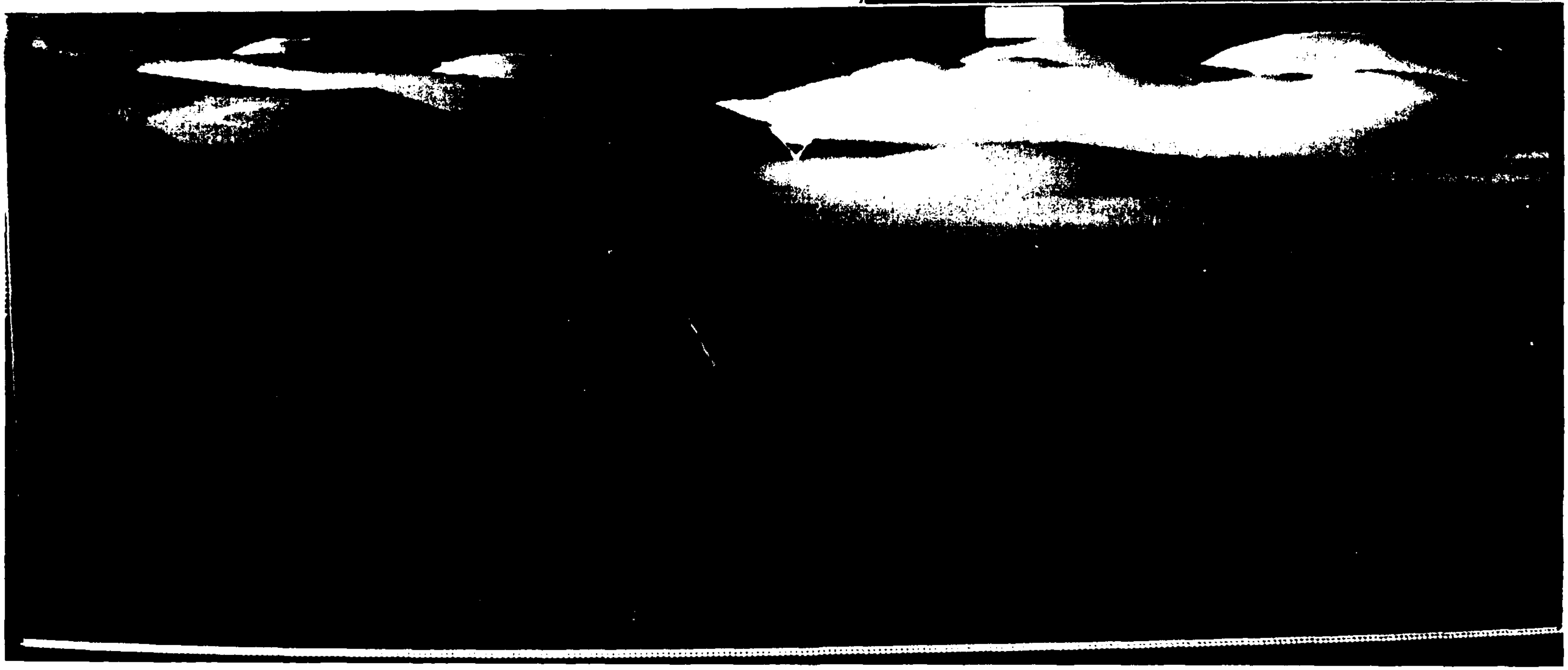


Figure 4-5. Sample plot from the Terrain Perspective Viewer (TPV) workstation software: planimetric and perspective views of gridded digital terrain models, created from DTED and displayed on a Sun Microsystems 3/160-C computer.



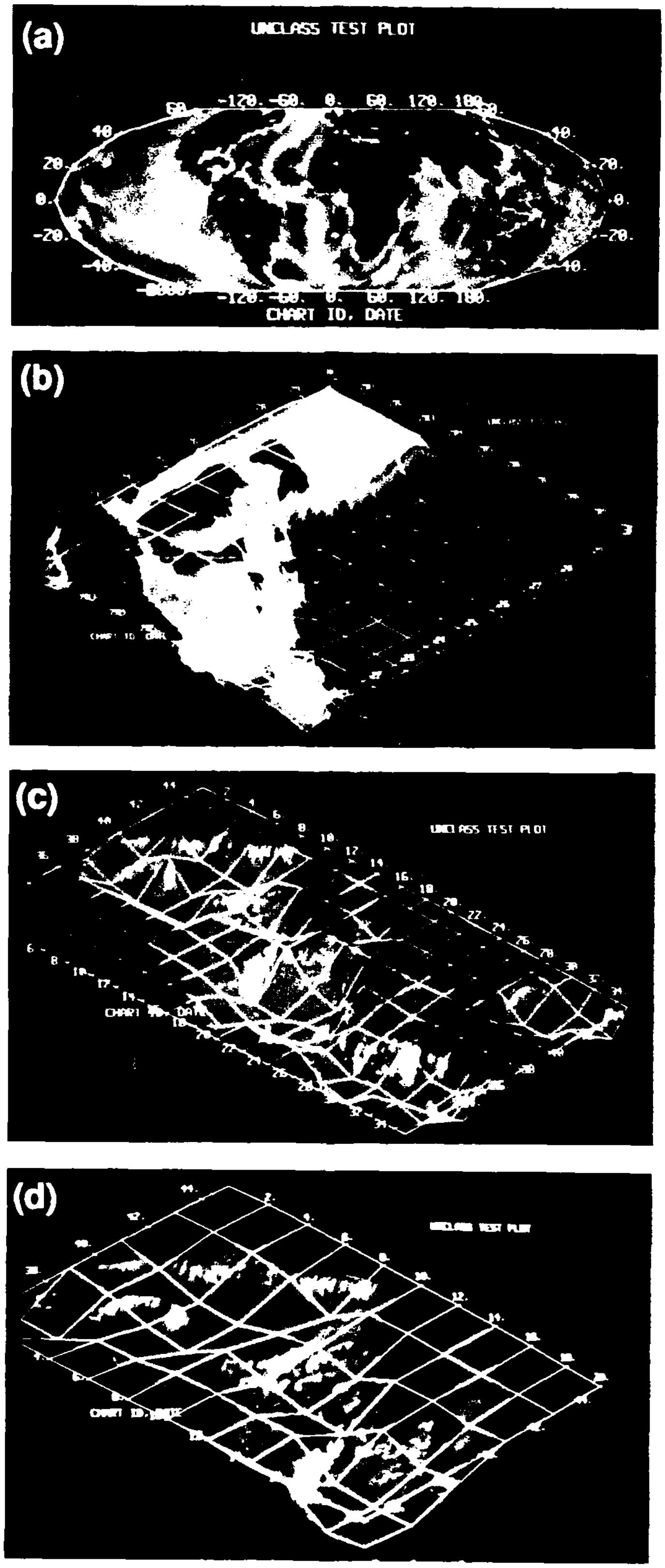


Figure 4-6. Sample plots created with Program Render, written by Jerry Landrum (NORDA Code 351) to be a device-independent computer mapping and graphics program: (a) Stereographic plot of the world, with bathymetry contoured with shaded relief; (b) 3-D view of continental shelf off the Bahama Islands (20-30°N, 280-290°W); (c) 3-D view of the Mediterranean Sea basin (30-46°N, 0-34°E); (d) Zoomed view of map (c) (34-46°N, 0-20°E).

4.5 Global Geomagnetic Project

The Global Geomagnetic Project (GEM) is analyzing spatial and temporal variations of geomagnetic field component annual means by using vector magnetic field component data measured at about 100 international magnetic observatories (McLeod, 1988). Using the PAL's VAX 11/780, spherical harmonic models of the magnetic data were computed for filtered time derivatives of the field by using data from a selected subset of the observatories (chosen for their relatively low noise levels). The NCAR graphics package was used to produce plots of the data and to map the locations of the selected magnetic observatories. Figure 4-7 presents sample plots of "First Field Derivative vs. Time"; Figure 4-8 is a map indicating the locations of the selected magnetic observatories. Both figures were produced on an LN03-PLUS laser printer.

4.6 Geophysical Airborne Survey System

The objective of the Geophysical Airborne Survey System (GASS) project is to build and install a system to conduct worldwide geophysical and hydrographic surveys from aboard a Navy airplane. The GASS system integrates a suite of sensors and control devices to collect and process the survey data. It will replace an existing system that has been used since 1970 and is now unsupportable. The new GASS is designed to be reliable, modular, and flexible, and to be able to operate under a wide range of environmental conditions encountered aboard the airplane.

Although most of the finalized GASS software is now being executed on the GASS' specialized UNIX system, much of the initial testing and development (before procurement and delivery of the GASS hardware) was done in the PAL. The GASS project still uses the VAX 11/780 for some software development

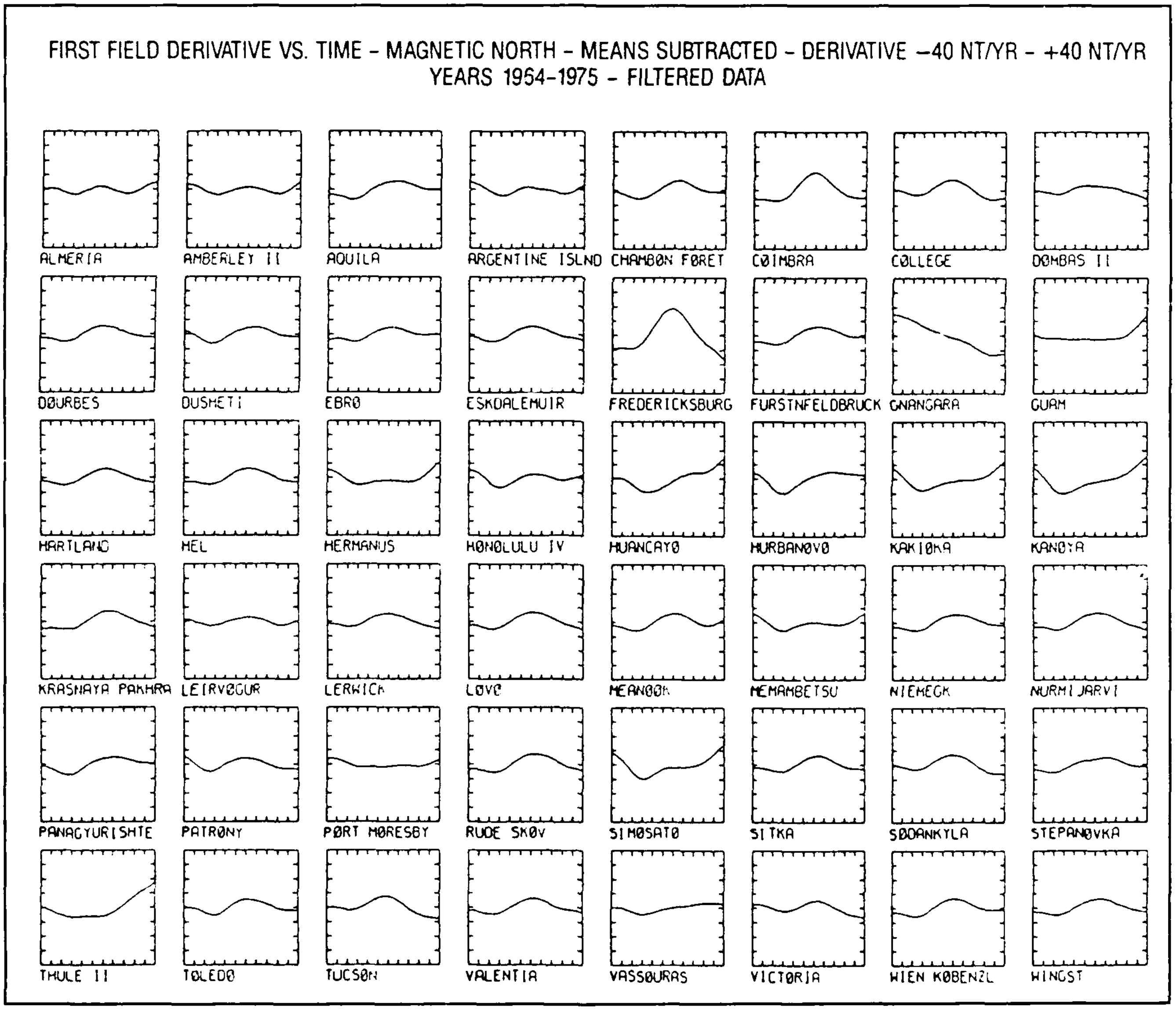


Figure 4-7. "First Field Derivative vs. Time," prepared by Malcolm McLeod (NORDA Code 352) using NCAR graphics software and LN03-PLUS laser printer.

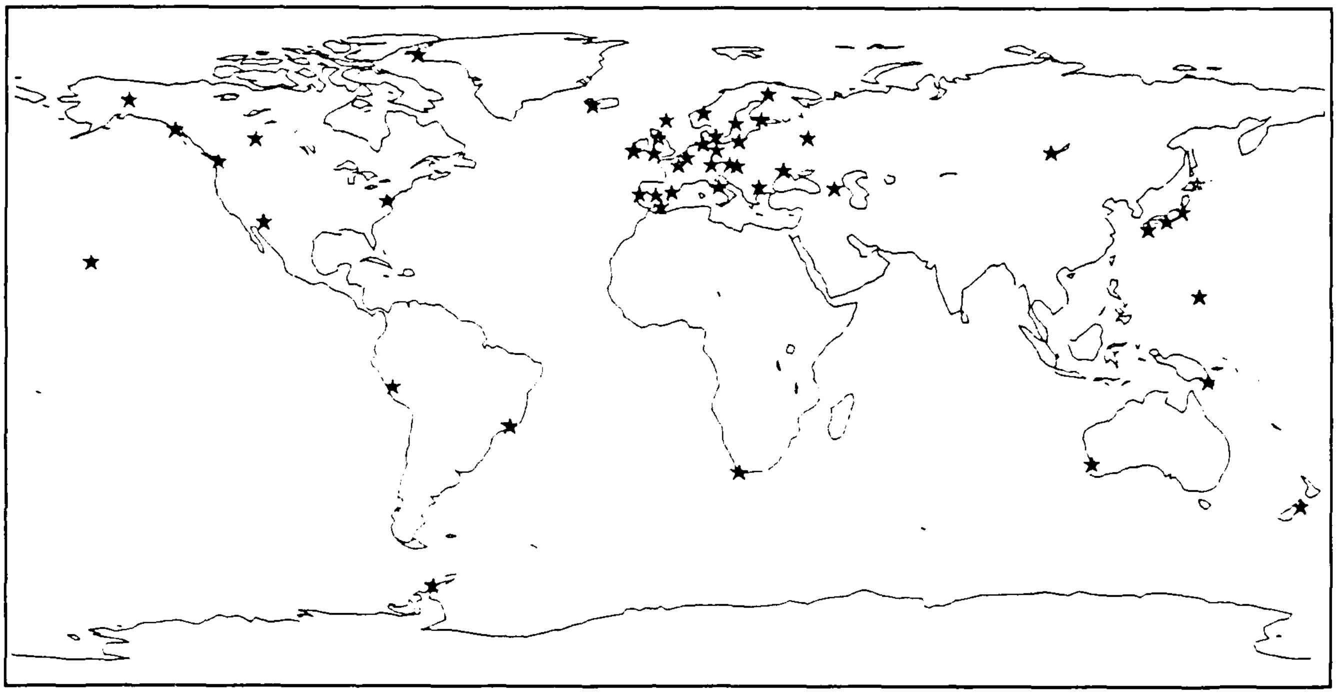


Figure 4-8. "Selected Magnetic Observatories," prepared by René Estes (NORDA Code 352) using NCAR graphics software and LN03-PLUS laser printer.

to make use of a superior debugging utility that is not available on the GASS computer. Due to the lack of peripherals on its system, GASS also uses the PAL computers for document processing, printing UNIX files, and transporting software. In particular, LN03-PLUS laser printers and exceptional text editing capabilities (such as the FRED editor) are used to prepare GASS reports and output program listings. Finally, the VAX 11/780 will continue to be used by GASS to verify data recording modules read from GASS-created magnetic tapes.

4.7 Map Data Formatting Facility

NORDA is developing the Map Data Formatting Facility (MDFF) to produce a data base of scanned map and chart images, digital terrain elevation data, and cultural feature data. This data base will be distributed as a library of Compact Disk-Read Only Memory (CD-ROM) optical disks, and it will be formatted specifically to permit a mission planning system to sample subsets of the data base for loading into the Digital Moving Map System of an aircraft (Shaw et al., in prep).

Prototype MDFF software was available for testing and evaluation long before most of the hardware was procured or installed, so the PAL facility provided MDFF scientists with a testing ground for some of the software. After the main MDFF computers were delivered (primarily VAX equipment, as in the PAL) the MDFF still lacked a display device. The PAL facility then provided MDFF scientists with an image processor and display devices for viewing and processing the scanned chart images (Fig. 4-9). Without the PAL facility, testing and evaluation of prototype MDFF software and display of prototype chart images would have been delayed by several months.

Since the MDFF surpasses the PAL in VAX computer power, future MDFF utilization of the PAL would center around the specialized, non-VAX computers, such as the Symbolics 3670, for knowledge based, computer-aided research into automated feature extraction techniques, base map enhancement techniques, and improved methods of map data compression. The MDFF may also require the Gould IP8500 for these research tasks until an image processor is procured for that project.

4.8 World Vector Shoreline

For the past 3 years, the PAL has contributed significantly to a joint NORDA-DMA effort in developing a new digital WVS data product. The WVS is a global 1:250,000 scale data base of shorelines, political boundaries, and country names that will supplant the CIA's World Data Base II as the Navy's standard shoreline data base.

In March 1986, DMA released a prototype WVS for the Navy to evaluate. NORDA focused on the suitability of the data base's content and its processing efficiency by using the VAX 11/780 in the PAL to design and execute various data processing functions for evaluating the data. The results of NORDA's evaluation were presented in two reports: one examined

Figure 4-9. Sample scanned chart (ADRG) image.

the data format, DMA's Standard Linear Format (Langran et al., 1986); the other evaluated the data base itself (Langran and Connor, 1986). In response to recommendations presented in these reports, DMA requested that NORDA assist them in designing a new WVS format and data structure that would best meet Navy requirements.

NORDA used the PAL computer facilities to develop a new format and data structure for WVS. This new prototype was again distributed to Navy users for review in March 1987. After favorable response from the reviewers (Lohrenz, 1988), DMA requested that NORDA write production software to convert digitized WVS vectors into the new format. The PAL was used as a developing and testing ground for this production software, and since it contained a compatible computer with DMA's facility (VAX 11), final executables could be tested at NORDA and sent to DMA for immediate use. This software was completed and delivered to DMA in June 1988.

Future utilization of the PAL in the WVS project includes further enhancement of the production software (particularly in error detection and semiautomated update procedures) and the development of software to selectively extract and display the data. Figure 4-10 shows a small-scale version of the prototype WVS area—the Mediterranean Sea—plotted with the NCAR plot package and output on the QMS laser printer.

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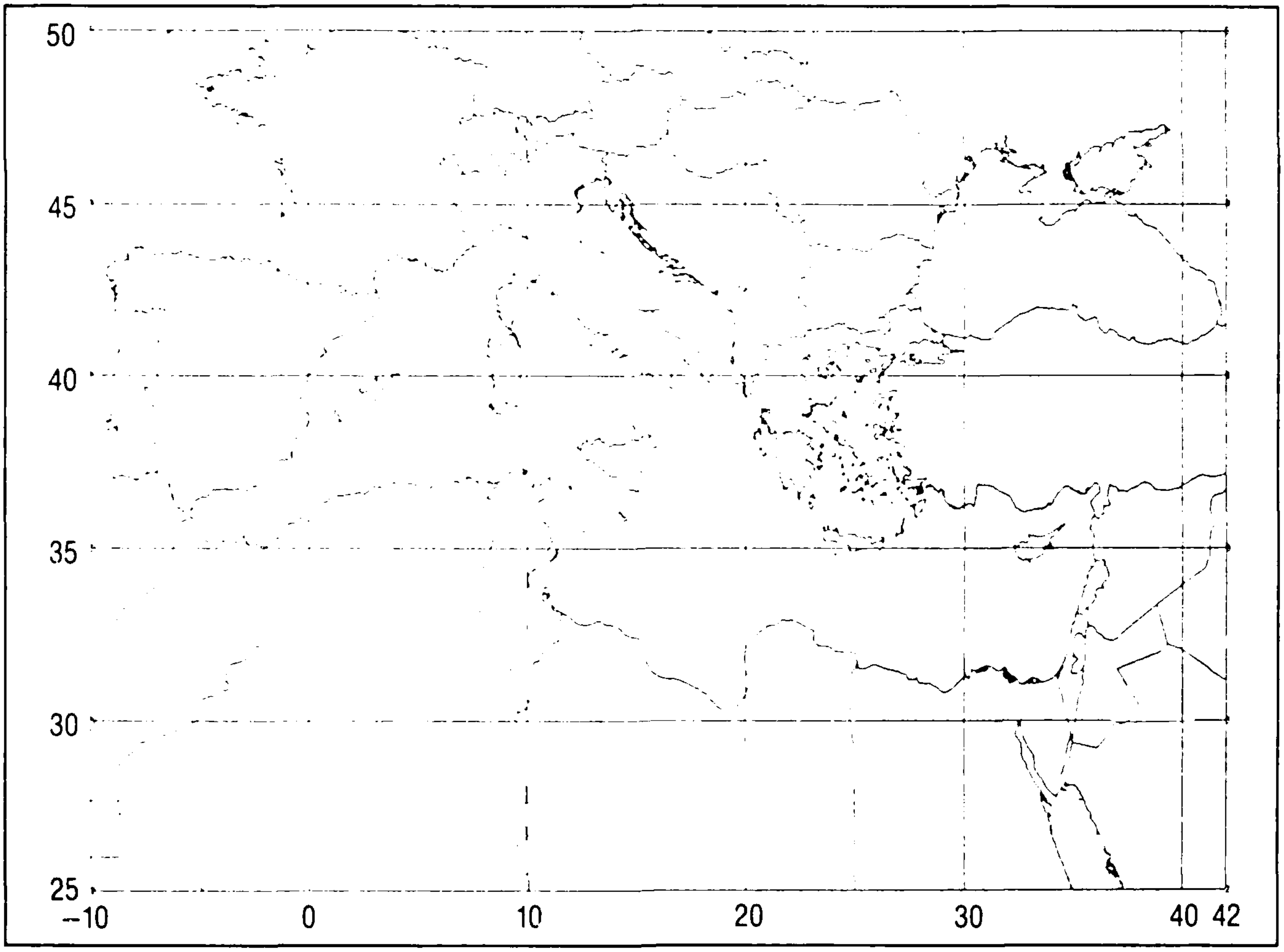

Figure 4-10. Prototype WVS plot: the Mediterranean Sea, created with NCAR graphics software on LN03 laser printer.

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Appendix A

List of PAL Hardware and Peripherals

I. CPUs and MAJOR COMPONENTS

1. VAX 11/780 with 10 Mbytes memory, 2.66 Gbytes disk space, Floating Point Accelerator, FPS 5205 array processor, Gould IP8500 image processor, and Eikonix digitizing camera system. 32 RS232 terminal ports, 32 ethernet terminal server ports. Computer operating system: VAX/VMS V4.6.

2. Silicon Graphics IRIS 3130 Workstation with 8 Mbytes main memory, 340 Mbytes disk space, Floating Point Accelerator, 1024 x 1024 x 32 addressable display memory (1024 x 768 viewable), 24 bit planes for color. Color monitor, 4 RS232 terminal ports and Ethernet access. Operating system: UNIX (Berkeley 4.2).

3. Sun 3/160-C Workstation with 4 Mbytes memory, 284 Mbytes disk space, 8 bit planes for color. Color monitor, 2 RS232 terminal ports and ethernet access. Operating system: UNIX (System V).

4. Symbolics 3672 Workstation with 6 Mbytes memory, 300 Mbytes disk space. Black/white monitor, 3 RS232 terminal ports and ethernet access. Operating system: LISP

5. Personal Computers (TOTAL: 31)
   - o 28 Zenith Z-248s, each with color graphics, 1 hard disk drive, 1 5.25" floppy drive. 32 printers. Terminal line connection to VAX 11/780 available.
   - o 1 IBM-PC with color graphics, 2 floppy drives, printer.
   - o 2 Macintosh-IIs, each with color graphics, 1 hard disk drive, 1 3.5" floppy drive, 1 graphics printer.

II. DISK STORAGE (TOTAL: 10 removable disks & 4 fixed disks; 3.45 Gbytes)

1.	VAX 11/780:	8 RA60 removable disk drives (205 Mbytes each)
		2 fixed, "quick-releasable" disk drive (512 Mbytes each
2.	IRIS:	2 fixed Wincester disk drives (170 Mbytes each)
3.	Sun:	2 fixed disk drives (142 Mbytes each)
4.	Symbolics:	1 fixed Wincester disk drive (300 Mbytes)

III. MAGNETIC TAPES (TOTAL: 3 mag.tape drives, 2 cart.tape drives)

1.	VAX 11/780:	2 9 track, 1600/6250 bpi magnetic tape drives
2.	IRIS:	1 9 track, 1600 bpi magnetic tape drive
		1 .25" cartridge tape drive
3.	Sun:	1 .25" cartridge tape drive
4.	Symbolics:	1 .25" cartridge tape drive

IV. TERMINALS (TOTAL: 41 terminals)

1. VAX 11/780: 1 hardcopy operator's terminal
   24 monochrome video terminals
   6 Tektronix color graphics terminals
   6 RGB color monitors for image processing

2. IRIS: 1 IRIS color graphics terminal/monitor
   1 VT102 terminal

3. Sun: 1 Sun color graphics terminal/monitor
   1 VT102 terminal

4. Symbolics: 1 Symbolics black/white terminal/monitor
   1 RGB color monitor

V. HARDCOPY OUTPUT DEVICES

1. VAX 11/780: 1 Printronix dot matrix printer
   1 QMS 1200 laser printer/plotter
   4 LN03-plus laser printers
   1 Tektronix 4696 color printer/plotter
   1 Tektronix 4632 Hard Copy Unit
   1 Benson pen plotter
   1 Numonics digitizing table
   1 Matrix camera system
   2 video lines to Seiko color hardcopier

2. IRIS: 1 Tektronix 4692 color printer/plotter
   1 video line to Seiko color hardcopier
   1 LN03-plus laser printer

3. Sun: none (but can access all others, except Seiko, via Ethernet)

4. Symbolics: 1 video line to Seiko color hardcopier

VI. COMMUNICATIONS

1. VAX 11/780: Ethernet to NORDA, SPAN and Internet networks
   8 dial-up modems (6 digital, 1 analog, 1 diagnostic)

2-4. IRIS, Sun and Symbolics: Ethernet access to each other;
   Fiber-optic Ethernet to NORDA, SPAN and Internet
   via node NORDA1 gateway.

Appendix B

List of Software Available in the PAL
(All software documentation and manuals are in the PAL)

Name & Description	Host Computers	Access & On-line Help
1. Program Compilers		
C	780, IRIS, Sun	$ CC program
FORTRAN	780, IRIS	$ FOR program
PASCAL	780	$ PAS program
2. Image Processing Programs		
AFES (UNIX)	(Not installed)	Tapes PA454, PA613
ELAS (VMS)	780	$ ELAS
ELAS (UNIX)	(On order)	
ERDAS (VMS)	780	$ ERDAS
ERDAS (MS-DOS)	Z-248 (On order)	
LAS (VMS)	780 (Not installed)	Tapes PA499-500,673,754
LIPS (VMS)	780	$ LIPS
3. Graphics Subroutine Libraries *		
BENSON plotter s/w	780	BENLIB.OLB
CERN math/graphics	780	DJA0:[COMMON.CERN]*.OLB
DIGITIZER (Eikonix s/w)	780	DIGITIZER.OLB
MOVIE.BYU 3D graphics	780 (Not installed)	Tape PA630
NCAR 2D, 3D graphics	780	NCAR.OLB, NCARUTIL.OLB
PLOT10 for Tek devices	780	PLOT10.OLB
QTEKPLOT (for QMS)	780	QTEKPLOT.OLB
SHADE light, shading	780 (Not installed)	Tape PA706
TRACER ray tracing	780	TRACER.OLB
IRIS graphics	IRIS	Fortran or C callable (See IRIS manuals)
SUN-CORE graphics	Sun	Fortran or C callable (See Sun manuals)
4. Math and Statistics Subroutine Libraries *		
IMSL library	780	SYS$IMSL:IMSLIB*.OLB
FPS array processor	780	DJA0:[FPS]*.OLB
5. Miscellaneous Utilities		
CALENDAR (NORDA events)	780	$ CALENDAR (menu-driven)
DIALER modem controller	780	$ R AUTO_DIAL:DIALER
DTC Desk Top Calendar	780	$ DTC (menu-driven)
FINDDEV device information	780	$ FINDDEV device_name
FINDTAPE tape information	780	$ FINDTAPE
FRED screen editor	780	$ FRED filename
FTCOPY (foreign tapes)	780	$ FTCOPY infile outfile
KERMIT file transfer	780, IRIS	$ KERMIT
VDRIVE VMS/MS-DOS link	780, Z-248	on PC: $\vdrive\vdrive
WHOIS user information	780	$ WHOIS user

* Libraries are Fortran-callable from SYS$LIBRARY unless otherwise noted

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ELAS (VMS)	780	$ ELAS
ELAS (UNIX)	(On order)	
ERDAS (VMS)	780	$ ERDAS
ERDAS (MS-DOS)	Z-248 (On order)	
LAS (VMS)	780 (Not installed)	Tapes PA499-500,673,754
LIPS (VMS)	780	$ LIPS
3. Graphics Subroutine Libraries *		
BENSON plotter s/w	780	BENLIB.OLB
CERN math/graphics	780	DJA0:[COMMON.CERN]*.OLB
DIGITIZER (Eikonix s/w)	780	DIGITIZER.OLB
MOVIE.BYU 3D graphics	780 (Not installed)	Tape PA630
NCAR 2D, 3D graphics	780	NCAR.OLB, NCARUTIL.OLB
PLOT10 for Tek devices	780	PLOT10.OLB
QTEKPLOT (for QMS)	780	QTEKPLOT.OLB
SHADE light, shading	780 (Not installed)	Tape PA706
TRACER ray tracing	780	TRACER.OLB
IRIS graphics	IRIS	Fortran or C callable (See IRIS manuals)
SUN-CORE graphics	Sun	Fortran or C callable (See Sun manuals)
4. Math and Statistics Subroutine Libraries *		
IMSL library	780	SYS$IMSL:IMSLIB*.OLB
FPS array processor	780	DJA0:[FPS]*.OLB
5. Miscellaneous Utilities		
CALENDAR (NORDA events)	780	$ CALENDAR (menu-driven)
DIALER modem controller	780	$ R AUTO_DIAL:DIALER
DTC Desk Top Calendar	780	$ DTC (menu-driven)
FINDDEV device information	780	$ FINDDEV device_name
FINDTAPE tape information	780	$ FINDTAPE
FRED screen editor	780	$ FRED filename
FTCOPY (foreign tapes)	780	$ FTCOPY infile outfile
KERMIT file transfer	780, IRIS	$ KERMIT
VDRIVE VMS/MS-DOS link	780, Z-248	on PC: $\vdrive\vdrive
WHOIS user information	780	$ WHOIS user

* Libraries are Fortran-callable from SYS$LIBRARY unless otherwise noted

Distribution List

Asst Secretary of the Navy
(Research, Engineering & Systems)
Navy Department
Washington DC 20350-1000

Chief of Naval Operations
Navy Department (OP-02)
Washington DC 20350-2000

Chief of Naval Operations
Navy Department (OP-71)
Washington DC 20350-2000

Director
National Ocean Data Center
WSC1 Room 103
6001 Executive Blvd.
Attn: G. W. Withee
Rockville MD 20852

Chief of Naval Operations
Navy Department (OP-987)
Washington DC 20350-2000

Oceanographer of the Navy
Chief of Naval Operations
Attn: OP-096
U.S. Naval Observatory
34th & Mass Ave., NW
Washington DC 20390-1800

Commander
Naval Air Development Center
Warminster PA 18974-5000

Commanding Officer
Naval Coastal Systems Center
Panama City FL 32407-5000

Commander
Space & Naval Warfare Sys Com
Washington DC 20363-5100

Commanding Officer
Naval Environmental Prediction
Research Facility
Monterey CA 93943-5006

Commander
Naval Facilities Eng Command
Naval Facilities Eng Command Headquarters
200 Stovall St.
Alexandria VA 22332-2300

Commanding Officer
Naval Ocean R&D Activity
Attn: Code 100
Stennis Space Center MS 39529-5004

Commanding Officer
Naval Ocean R&D Activity
Attn: Code 125L (13)
Stennis Space Center MS 39529-5004

Commanding Officer
Naval Ocean R&D Activity
Attn: Code 125P (1)
Stennis Space Center MS 39529-5004

Commanding Officer
Naval Ocean R&D Activity
Attn: Code 105
Stennis Space Center MS 39529-5004

Commanding Officer
Naval Ocean R&D Activity
Attn: Code 115
Stennis Space Center MS 39529-5004

Commanding Officer
Naval Ocean R&D Activity
Attn: Code 200
Stennis Space Center MS 39529-5004

Commanding Officer
Naval Ocean R&D Activity
Attn: Code 300
Stennis Space Center MS 39529-5004

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The Mapping, Charting and Geodesy (MC&G) Division at the Naval Ocean Research and Development Activity (NORDA) is the primary activity within the U.S. Navy for conducting research and development (R&D) in direct support of naval MC&G requirements. MC&G projects include R&D in the general areas of charting, remote sensing, bathymetry, geophysics, photogrammetry, reconnaissance, and ocean surveillance in support of the U.S. Navy, the U.S. Marine Corps, and the Defense Mapping Agency.

NORDA's Pattern Analysis Branch, MC&G Division, is concerned with all aspects of digital MC&G data, including hardware, software, and data bases. The primary computing facility of this branch is the Pattern Analysis Laboratory (PAL). This report describes the configuration of the PAL, its current and anticipated capabilities, and its role in naval MC&G projects.

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